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PREFACE: THE MOUNTAIN CRYOSPHERE – A HOLISTIC VIEW ON PROCESSES AND THEIR INTERACTIONS

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This thematic issue of *Geografiska Annaler: Series A, Physical Geography* is dedicated to Professor Wilfried Haeberli on the occasion of his retirement in January 2012. Paraphrasing the wide and integrative scope of his scientific work, it is titled 'The mountain cryosphere – A holistic view on processes and their interactions' and contains contributions arising from keynote papers of a symposium held in Zurich with the same name on 20 January 2012.

The scientific work of Wilfried Haeberli (Fig. 1) began with his PhD at the University of Basel, Switzerland. After this, Wilfried Haeberli started to work at the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) at the Swiss Federal Institute of Technology Zurich (ETHZ) in 1974 and became head of its Glaciology Section in 1988. In 1978/1979 he worked with Mark Meier as visiting scientist at the US Geological Survey in Tacoma, Washington and Fairbanks, Alaska. From 1995 until 2012 Wilfried Haeberli was Full Professor for Physical Geography at the University of Zurich. The influential figures in his early career include Hans Oeschger, Bruno Messerli, Herfried Hoinkes, and his PhD advisor Dietrich Barsch.

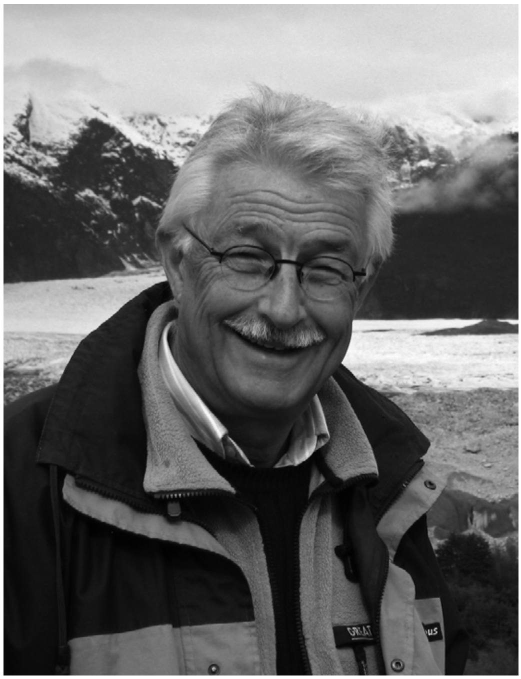

Fig. 1. Wilfried Haeberli during an excursion to the northern Patagonian ice field. Photo: 11 September 2009, Amanda Maxwell.

Scientific contribution

In his PhD, Wilfried Haeberli investigated the distribution of permafrost in an Alpine test area (Flüelapass, Eastern Switzerland). Then a marginal and exotic research topic with only few previous studies, it is much due to his work that mountain permafrost research has now developed into an important field in science and practice. The publication of the BTS (Bottom Temperature of the winter Snow cover) method (Haeberli 1973) and the so-called rules-of-thumb in his PhD (Haeberli 1975) provided a basis for the spatial delineation of permafrost occurrence in mountains. Aided by GIS modelling, this also enabled spatial estimates (Keller 1992; Hoelzle *et al*. 1993; Hoelzle and

Haeberli 1995; Haeberli *et al*. 1996) visualized as maps to communicate the topic to a broader audience. The investigation of rock glaciers took him from an initial reconstruction of previous research (Fisch *et al*. 1978) over detailed studies of internal structure (Haeberli 1985a), photogrammetric analyses of surface displacement (Haeberli and Schmid 1988), analyses of material composition (Haeberli *et al*. 1999a) to thermal characteristics (VonderMühll and Haeberli 1990) to a broad and detailed state of the art summary given three decades later (Haeberli *et al*. 2006). Drilling in rock glaciers has been pioneered and promoted (Barsch *et al*. 1979; Haeberli *et al*. 1988; 1998). The interaction with glaciers (Haeberli 1979; 1983; 2005), and more generally the role of permafrost in the conditioning of landforms (Haeberli 1996; Gruber and Haeberli 2007) have been recurring themes. A summary of these four decades of mountain permafrost research is given by Haeberli *et al*. (2010).

In the aftermath of the Mattmark ice avalanche that killed 88 construction workers in 1965, and with the expansion of hydropower schemes and other infrastructure, the assessment and understanding of hazards related to glaciers and permafrost gained importance in Switzerland. Early in his career, Wilfried Haeberli performed corresponding research (Haeberli and Röthlisberger 1976; Haeberli 1977; Haeberli *et al*. 1979, 1989a) that was often tied to consulting mandates. Flooding and debris flows in many areas of Switzerland during the summer of 1987 caused considerable damage (Naef *et al*. 1989; Haeberli *et al*. 1990) and triggered continued interest in the role of permafrost degradation in debris flow conditioning (Zimmermann and Haeberli 1992) that was continued in a national research programme (Haeberli *et al*. 1999b). Together with the beginning interest in permafrost in steep bedrock (Haeberli *et al*. 1997; Wegmann *et al*. 1998) this was one foundation for the EU FP6 research Programme PACE (Harris *et al*. 2009). The expertise on combined assessment of glacier and permafrost hazards has also found important foci outside Switzerland (Haeberli *et al*. 2002, 2004a; Huggel *et al*. 2007).

Early in his career, Wilfried Haeberli also started research on ice temperatures of high-elevation Alpine summits, demonstrating that cold ice, and thus the potential for retrieving ice cores as environmental archives, existed (Haeberli 1976). From this, a continued interest in Alpine paleoglaciology followed in the directions of ice-core analyses (Oeschger *et al*. 1978; Haeberli *et al*. 1983, 1988) and reconstructions of past glacial environments (Haeberli and Penz 1985; Lister *et al*. 1998). Besides ice cores from cold firn areas, cold miniature ice caps formed by superimposed ice provide a further valuable environmental archive (Haeberli *et al*. 2004b). More recent investigations of firn temperatures (Suter *et al*. 2001) supported the conclusion, that not only many miniature ice caps, but also the high-elevation cold firn areas may be lost as environmental archives during coming decades. The connection between firn and ice temperatures, permafrost and natural hazards is explored in several examples (Haeberli *et al*. 1999b; Hasler *et al*. 2011).

In 1983, Wilfried Haeberli became director of the Permanent Service on the Fluctuations of Glaciers, marking the beginning of his three-decade long contribution to international cryosphere and climate monitoring. As a scientist and in his role as the first director of the World Glacier Monitoring Service established in 1986, he made key contributions to the design and implementation of national (Haeberli *et al*. 1993) and global (Haeberli 1985b; Haeberli *et al*. 1989b, 2007; Brown *et al*. 2001; Paul *et al*. 2009) monitoring strategies and systems, as well as their international coordination (Townshend *et al*. 1995; Haeberli *et al*. 2000). In this, he also continued to promote the interpretation of long-term length change measurements (Hoelzle *et al*. 2003) and the systematic use of satellite observations as spatial complements of point-based mass-balance observations (Kieffer *et al*. 2000; Paul *et al*. 2002; Haeberli 2004). This, and the estimation of high-resolution digital elevation models of glacier beds including the modelling of potential future lakes in deglaciating high-mountain regions (Linsbauer *et al*. 2009; Frey *et al*. 2010) is in many ways based on early analyses of inventory data (Haeberli and Hoelzle 1995) that established methods for the evaluation of large samples of glaciers. As co-author and reviewer, he has been actively involved in the compilation of the first four IPCC assessment reports and was committed to the communication of cryosphere-climate interactions (Haeberli 1994; Fischlin and Haeberli 2008; Haeberli and Zemp 2010; Ajai *et al*. 2011).

During his career, Wilfried Haeberli has also taught and inspired many students and young researchers, and though collaboration and joint research contributed to shaping his scientific field.

Content of this issue

The contributions in this issue concern differing topics related to mountain cryosphere processes and phenomena and outline important new directions for research. In the outlines given below and in the contributions themselves, the relation to the work of Wilfried Haeberli is directly evident.

Mountain glaciers are iconic indicators of climate change but the combined and quantitative use of their length changes as a climate proxy remains challenging. This is because differences in size, topography and environmental conditions lead to variations in the magnitude and timing of the response of individual glaciers to regional forcing. Oerlemans (2012) uses a model for representing glacier length fluctuations with only two parameters that relate to sensitivity and response time. This simplicity enables extracting information on climate forcing and glacier parameters from ensembles of glacier records. Results are encouraging in terms of an agreement between forcings reconstructed from neighbouring glaciers, but some differences to forcing inferred from station data exists.

While permafrost research is an important topic in North America, mountain ranges there have received only marginal interest. Lewkowicz *et al.* (2012) describe a unique set of ground and air temperature measurements and a derived spatial model of permafrost in the southern Yukon and northern British Columbia, Canada. They show how winter inversions, which usually influence air temperature gradients below the tree line in valleys, have a dominating influence on the spatial distribution of permafrost and further complicate modelling in mountains. Based on the transfer functions between ground and air temperatures derived from their measurement network, they also argue that local surface and subsurface conditions add to the strong heterogeneity of ground temperatures and will result in differing patterns of temperature evolution in the future.

Rock glaciers are prominent landforms indicative of mountain permafrost and recently have received increased interest in the context of hazard assessment. Using diverse examples, Springman *et al.* (2012) provide an overview of current process studies aimed at understanding the observed recent acceleration and beginning collapse of many rock glaciers. They describe in-situ and laboratory geotechnical testing and measurements of deformation and temperature in the field as well as combined modelling of mechanical stability, thermal regime, and water flow. From the studies presented it is evident that broad multidisciplinary teams are needed to advance our understanding of the processes involved in rock-glacier degradation.

In glacierized high-alpine areas, non-temperate glaciers may be unique in holding climate signals linked to past atmospheric changes. Because the Alps are surrounded by the major European anthropogenic emission sources, their glaciers are not only an archive for climatic characteristics but also particularly for man-made changes in atmospheric composition. Wagenbach and Preunkert (2012) discuss results from two major coring areas (located in the summit ranges of Monte Rosa and Mt Blanc massif) which largely differ in their snow accumulation rate, and hence, in their accessible time scales. When investigating Alpine ice cores, the intricate role of seasonality of specific compounds (particularly $\partial^{18}O$) and snow erosion have to be taken into account. Furthermore, an appropriate dating of e.g., the basal layer, for tracing ice formation and landscape evolution is still a major challenge. The adequate application of dating tools to reconstruct the earliest stages of a glacier is particularly intriguing in view of cold, low-elevation miniature ice-caps.

Besides the cold ice found at highest elevations, the Mont Blanc massif provides many more examples of changing cryosphere systems. Deline *et al.* (2012) provide an overview of current knowledge concerning recent and Holocene changes of glaciers and permafrost, as well as their impact on geomorphic phenomena, and ultimately, natural hazards. In this area that has been well documented photographically due to tourism during the past century, clear indication for increasing rock fall activity related to warm periods on decadal and annual scales exist. A large number of ice-bearing fractures has been observed in the detachment areas of rock falls, further supporting the hypothesis that permafrost degradation is an important element in explaining the cause of this increase. The accelerated glacier retreat in the area led to a strong increase in the debris cover on glaciers, providing a self-retardation effect that has reduced summer melt. The discussed glacial hazards are related to ice fall and effects caused by the outburst of glacial lakes and water pockets. Despite the widespread glacier melt, these hazards are unlikely to significantly decrease during the coming decades.

All the contributions are closely related to Wilfried Haeberli's scientific interest and activities and are a tribute to the leadership and inspiration given by him during the past four decades – one part of his scientific legacy.

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